IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Appl. No.	:	10/699,212	Confirmation No.: 2780
Applicant	:	David R. Hennings et al.	
Filing Date	:	October 30, 2003	
Title	:	Endovenous Closure of Varicose Veins with Mid-Infrared Laser	
Group Art Unit	:	3769	
Examiner	:	David M. Shay	
Docket No.	:	15487.4002	
Customer No.	:	34313	

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DECLARATION OF DAVID R. HENNINGS

1. I am President and CEO of CoolTouch, Inc., the assignee of the above-identified patent application and I am one of the inventors named in that application.

2. I have reviewed the Examiner's Answer dated November 13, 2008 which has been received in this application.

3. I am familiar with the Min and Proebstle articles from the scientific literature attached as Exhibits A, B and C to the Geriak Declaration filed in this application.

4. I have had 30 years of experience in the design, development and use of laser-based devices for medical applications and 6 years of such experience with regard to lasers used for treatment of varicose veins.

5. I am familiar with the scientific literature relating to the use of lasers for medical applications and such literature relating to the use of lasers for the treatment of varicose veins.

6. The articles from the scientific literature attached as Exhibits A, B and C to the aforesaid Geriak Declaration are fully representative of the prior art with respect to varicose vein treatment and are from highly respected scientific journals.

7. Attached hereto as Exhibit 1 is a true and correct copy of an article by Doctors Fan and Rox-Anderson which appeared in the highly regarded scientific journal *Phlebology* in 2008. Dr. Rox-Anderson is one of the preeminent physicians in the field of interventional radiology, which includes the treatment of varicose veins.

8. The Fan/Rox-Anderson article attached hereto cites to the two Proebstle articles, Exhibits B and C to the aforesaid Geriak Declaration, in footnotes 7 and 14, respectively. The Fan/Rox-Anderson article also cites to articles from the *Journal of Vascular and Interventional Radiology* in footnotes 12, 21 and 22, which is the same journal in which the Min article attached as Exhibit A to the aforesaid Geriak Declaration.

9. The Fan/Rox-Anderson article also cites to Navarro Patent No. 6,398,777 (which the Examiner states to be of "little moment" at page 9 of the Examiner's Answer), but does not mention or cite to any of the irrelevant prior art relied upon by the Examiner. Furthermore, at page 209 of the Fan/Rox-Anderson article, the authors contrast the performance of a laser having a wavelength of 1320 nm with lasers having wavelengths of 810-1064 nm and conclude that there appears to be substantial patient benefit which results form the use of a wavelength of 1320 nm as recited in the claims of this application as compared with the 810-1064 nm wavelengths used by the prior art.

10. Based on my own first-hand knowledge, I can state unequivocally that the Examiner was incorrect in refusing, at page 11 of the Examiner's Answer, to accept the assertions of our counsel, Mr. Geriak, that Exhibits A, B and C to his Declaration were representative of the prior art. Furthermore, I

believe that the Fan/Rox-Anderson article attached hereto is fully consistent with the fact that Exhibits A, B and C attached to the aforesaid Geriak Declaration are representative of the prior art.

Further, Declarant sayeth not.

I declare under penalty of perjury that the foregoing is true and correct. Executed this 22 day of Dec, 2008 at Roseville, California.

David R. Hennings

EXHIBIT 1

EXHIBIT 1

Endovenous laser ablation: mechanism of action

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Abstract

Objectives: The objective of this study is to review the basics of laser and established tissue response patterns to thermal injury, with specific reference to endovenous laser ablation (EVLA). This study also reviews the current theories and supporting aspects for the mechanism of action of EVLA in the treatment of superficial venous reflux.

Methods: The method involves the review of published literature and original investigation of histological effects of 810 nm and 980 nm wavelength EVLA on explanted blood-filled bovine saphenous vein in an *in vitro* system.

Results: The existing histological reports confirm that EVLA produces a transmural vein wall injury, typically associated with perforations and carbonization. The pattern of injury is eccentrically distributed, with maximum injury occurring along the path of laser contact. Intravenous temperature monitoring studies during EVLA have confirmed that the peak temperatures at the fibre tip exceed 1000°C, and continuous temperatures of at least 300°C are maintained in the firing zone for the majority of the procedure. Steam production during EVLA, which occurs early in the photothermolytic process when temperatures reach 100°C, accounts for only 2% of applied energy dose, and is therefore unlikely to be the primary mechanism of action of thermal injury during the procedure.

Conclusion: EVLA causes permanent vein closure through a high-temperature photothermolytic process at the point of contact between the vein and the laser.

Keywords: endovenous laser treatment; varicose veins; endovenous technique

Introduction

Endovenous thermal ablation by either laser or radiofrequency ablation has emerged as an effective minimally invasive treatment of lower extremity superficial venous reflux disease and has largely replaced surgical vein stripping as first-line treatment for superficial venous reflux, with successful initial closure rate of 95–100%. When laser is used as the heating element (endovenous laser ablation or EVLA), the outcomes appear to be durable with a persistent closure rate of 94–97%.[1–3] Despite its widespread popularity, the mechanism of action of EVLA continues to be a point of investigation and discussion, and optimal energy and wavelength parameters to produce vein closure while minimizing postprocedural ecchymoses and discomfort remain to be determined. The purpose of this article is to provide an overview of the current theories of the mechanism of action of EVLA, with the intent of providing practitioners with a background information and understanding that may assist in refining procedural techniques. Points of discussion will include basic laser mechanics, principles of laser–tissue interactions with particular focus on the specifics of the EVLA setting, and review of the current theories and supporting data of the proposed mechanisms of action of EVLA.

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Laser mechanics

The term laser is an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers are available in wavelengths ranging from long far-infrared to short x-rays and any specific laser is monochromatic, emitting light of a single wavelength usually

expressed in nanometers (nm). Other characteristic features of laser light are that it is coherent (in phase), collimated to near parallel direction and tightly focused conferring high power density to the beam. Both pulsed and continuous beam emission have been used for EVLA.

Laser energy is expressed in units of joules (J) and energy density is the joules per square centimetre (J/cm^2). Power is expressed in watts (W) defined as joules per second (W = J/second) and the power density is the watts per square centimetre (W/cm^2). The irradiance of a laser is defined as the power of light emitted divided by beam cross-sectional area (W/cm^2). Irradiance represents the power per unit area of a single pulse of laser energy onto the target. The energy fluence is irradiance over unit time: laser power (W) × pulse duration (seconds) divided by laser beam cross-sectional diameter. Spatial energy fluence represents total energy dose during a treatment and is defined as power (W) × number of pulses × exposure time (seconds) divided by size of the treatment area (cm^2). Of note, spatial energy fluence represents energy delivery to a flat cross-sectional surface area. In EVLA, the energy is delivered to a tubular structure during active withdrawal of the firing fibre, a configuration that makes actual spatial energy fluence calculations cumbersome to perform. It is therefore often customary to express EVLA energy dose as joules per centimetre of vein treated (J/cm), a parameter that has been referred to as the endovenous fluence equivalent.

All laser systems have four basic components: the lasing medium, a resonating or optical cavity, an energy supply and a delivery system of optical fibres or mirrors. Lasing mediums can be solids (ruby or Nd-YAG), gases (helium, chlorine, argon, krypton, carbon dioxide, xenon), organic dyes (rhodamine 6G) or semiconductors (diode lasers).[4] Most commonly, the commercially available lasers for EVLA are diode lasers (810, 940 and 980 nm) or Nd:YAG lasers (1064, 1320 nm) with 500–600 μm diameter optical fibre delivery systems. The outer surface of the optical fibre is coated with a reflective material (cladding), which in turn is encased in a plastic covering that terminates 2–3 cm proximal to the emitting end of the fibre (Figure 1). The light-emitting surface for fibres, commonly used with diode lasers for EVLA, is usually flat and perpendicular to the long axis of the fibre. During EVLA, intense heating at the tip can cause fibre degradation with loss of cladding (Figure 2) and melting of the flat emitting surface. This may permit light emission from the sides of the fibre and loss of fluence at the tip as the procedure progresses. For the Nd:YAG lasers, diffusion tip fibres have been used to facilitate circumferential application of energy.

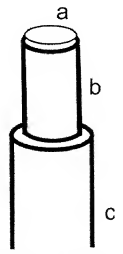

Figure 1 Schematic diagram of the flat tip optic laser fibre: (a) Flat light-emitting surface; (b) reflective cladding; (c) plastic coating on fibre shaft

Laser–tissue interactions: general concepts

Biological tissue is a complex amalgam of connective tissue and cells, and contains light absorbing

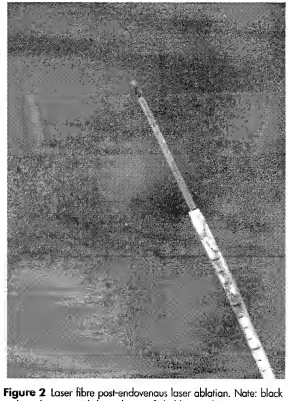

Figure 2 Laser fibre post-endovenous laser ablation. Note: black carbon deposits and degradation of cladding at the tip

elements known as chromophores, each of which absorbs light in a specific part of the electromagnetic spectrum. Examples of naturally occurring chromophores include melanin, haemoglobin, carotenoids and water. A photon passing through the tissue generates no tissue effects until it is absorbed by a wavelength-specific chromophore, resulting in molecular excitation of the chromophore to a higher energy state. De-excitation of the chromophore releases this energy back into the tissue, causing tissue change through both photochemical and photothermolytic mechanisms.

In photochemical reactions, the released energy causes a chemical reaction such as oxygen-free radical generation, which in turn results in local phototoxicity and tissue damage. In photothermolysis, the de-excitation energy is released as heat into the immediate surrounding tissues. The technique of applying a specific wavelength of light to target a specific chromophore for thermal ablation of a specific tissue structure is termed selective photothermolysis, and is a unique and powerful feature of laser therapy. The severity of thermal damage produced in a target reflects the cumulative effect of the total energy delivered, and is a function of both intensity and duration of the thermal insult. The generation of high temperatures for short duration may produce similar effect as lower temperature insult applied for longer duration.

Intermittent (pulsed) cycle lasering is one technique that may enable thermal energy accumulating in the target to dissipate through conduction into the surrounding tissues between laser applications. This can potentially maximize the thermal effects on the target while limiting heating of the non-target surrounding tissues.[5] Pulsed-laser technique was initially used in the early clinical experience with EVLA. However, owing to concerns about regional overtreatment and perforations, as well as undertreatment of skipped segments with pulsed mode firing, continuous mode firing has evolved as the preferred method of laser application for EVLA.

The cellular response of biological soft tissue to progressive heating follows a well-described sequence of events. Prolonged heating at 42–45°C results in sublethal cellular damage, which is reversible. Above 50–60°C, irreversible damage in the form of protein denaturing, coagulation and necrosis occurs. At 90–100°C, tissue water vaporizes resulting in steam production and tissue desiccation. Above 300°C, carbonization with charring results.[5] As noted previously, heat from the target site dissipates by conduction through the surrounding tissues. Therefore, although the most severe thermal effects occur at the target epicentre, a zone of milder thermal effects and oedema typically circumscribes the target.

Thermal temperature extremes and tissue effects of EVLA

Medical lasers mostly utilize light from the visible and infrared portions of the optical electromagnetic spectrum. In the current state of EVLA technology, lasers with wavelengths of 810, 940, 980, 1064 and 1320 nm have all been successfully used for saphenous vein ablation.[1,6–9] Haemoglobin and to a lesser extent myoglobin in vein wall smooth muscle components are the dominant chromophores at the lower end of this range, while at 1320 nm wavelength water dominates as the energy-absorbing molecule.[6,9]

Weiss *et al.*[10] examined the gross tissue effects and tissue temperatures generated during EVLA with 810 nm diode laser in an *in vivo* goat model. Using thermal sensors mounted adjacent to the laser optical fibre, he determined that mean temperature at the firing tip was 729°C (peak 1334°C). The intense thermal heating zone appears to be focally situated around the laser tip: 2 mm proximal and distal to the fibre tip, the mean temperature decreased to 231°C and 307°C, respectively, and at 4 mm distal from the fibre tip, the mean temperature decreased to 93°C. Recently, Disselhoff *et al.*[11] confirmed Weiss' findings with intravascular temperature measurements during EVLA in an *in vitro* system.

Despite the intense heat at the laser tip, the thermal heating zone is predominantly contained within the lumen of the vein. Zimmet *et al.*[12] demonstrated in a swine model that during EVLA with 810 nm diode laser, ear vein outer wall temperatures ranged from 40 to 49.1°C. In hind extremity veins, he showed that with tumescent anaesthesia, the external vein wall temperatures never exceeded 40°C, compared with the baseline temperature of 33°C. These findings were corroborated by Beale *et al.*[13] in 12 human subjects in whom he inserted thermocouples percutaneously, positioned at 3, 5 and 10 mm distance from the short saphenous vein after administration of tumescent anaesthesia. He recorded temperatures during EVLA with 810-nm diode laser, using one-second pulse application at 12 W and fibre withdrawal rate of 3 mm/s. Beale found minimal heating of the perivenous tissues, with peak temperatures of 43.3°C, 42°C and 36°C at 3, 5 and 10 mm, respectively. The median temperatures at each of these locations were 34.5°C, 33.7°C and 31.1°C, respectively.

One would anticipate that with the average fibre tip temperatures exceeding 700°C, the tissue effects

of EVLA should reflect the complete spectrum of changes described previously, i.e. collagen denaturing, steam formation with tissue desiccation and carbonization (charring). These findings are indeed seen in cases of veins explanted following EVLA. Weiss noted in his goat vein explants that EVLA consistently resulted in transmural perforations and blood extravasation, associated with carbonization at each of the holes.[10] Oh *et al.*[8] performed histological evaluation on avulsed human great saphenous veins following EVLA, and noted the presence of transmural perforations, carbonization, endothelial damage and desiccation with vacuolization of the vessel media. Both Proebstle and Weiss noted that after EVLA, these thermal injuries were not circumferentially uniform, and were characterized by severe tissue lysis, charring and perforation at the site of presumed laser impact, with lesser thermal damage on the contralateral wall.[10,14] An example of a longitudinal transmural charred perforation from EVLA is presented in Figure 3.

Figure 3 Post-endovenous laser ablation saphenous vein fragment demanstrated charred longitudinal linear perforation along laser contact path

Special consideration must be given to EVLA with 1320 nm Nd:YAG laser. At this wavelength, the dominant chromophore is water and, as the biological tissue is largely composed of water, deeper energy penetrance and photothermolytic effect can be achieved at a lower fluence. Compared with 12–15 W power settings typically used during EVLA with 810–1064 nm wavelength light, EVLA at 5 W with the 1320 nm laser has been shown to be effective at 12-month follow-up for closing saphenous veins <12 mm in diameter.[6,9] At this higher wavelength and lower energy application, clinical evidence of perforation (pain, bruising) appears to be reduced.

EVLA mechanism of action

The exact mechanism of action of EVLA has been a topic of investigation and interest for several years and, to date, two theories have been proposed: (i) the steam bubble theory, and (ii) the direct contact theory.

Steam bubble theory

In EVLA, turbulent hyperechoic bubbles clearly form at the laser tip during energy application. Proebstle *et al.* investigated this phenomenon in an *in vitro* system using a blood-filled 6 mm diameter silicon tube. EVLA was performed with increasing pulsed doses of energy, and the volume of steam produced was collected and quantified. He found that a 15 J pulse of energy resulted in the formation of a 6 mm diameter steam bubble. He also noted that the volume of steam generated increased linearly with total energy delivery and that, in the absence of blood (saline-filled system), the laser did not incite steam formation. In a separate study of two patients who underwent experimental EVLA prior to GSV stripping, Proebstle performed EVLA with a saline-filled vein in one and with a blood-filled vein in the other. He noted focal injury at the point of laser impact in both, but additional circumferential damage in the blood-filled vein. Based upon these findings, Proebstle proposed that the primary mechanism of action for EVLA was thermal injury mediated by contact of steam with the vein wall, resulting in thrombotic closure of the vein.[7,14]

Although initially widely accepted as an explanation for the EVLA mechanism of action, upon further consideration, the steam bubble theory appears to be flawed as it fails to account for the majority of energy delivered to the vein in EVLA,

and it fails to explain how the high temperature phenomenon of carbonization occurs. Based upon the physical properties of water, 2.5 J of energy is required to convert 1 mm^3 of water to 1700 mm^3 of steam at atmospheric pressure. In Proebstle's experiment, a 15 J pulse produced a 6 mm diameter steam bubble, which he estimated would correlate with a 170 mm^3-volume of steam. At 100% efficiency, 15 J of energy should produce 10,200 mm^3 of steam; so based upon that ratio, the 170 mm^3-bubble accounts for only 1.6% of the 15 J of energy delivered. Steam produced during EVLA is also unconstrained, and dissipates readily through tributary and perforator branches, transmural perforations in the vein wall and via the unligated saphenofemoral junction. In this unpressurized state, it would be impossible for steam to superheat and achieve a temperature significantly higher than 100°C. Carbonization, which has been a consistent finding by numerous investigators in post-EVLA veins, requires temperatures in excess of 300°C to occur, implying the generation of intense heat and high temperatures during EVLA that cannot be attributed to thermal effects of unpressurized steam.

Direct contact theory

In their original patent application for EVLA,[15] Navarro *et al.* proposed a system for saphenous vein occlusion by application of laser energy to the vein wall, mediated by direct contact between the emitting surface of the fibre and the vein. Specific objectives of the patent included delivery of intraluminal laser energy through direct contact with the vein wall, minimizing clot formation and maximizing vein wall damage during the procedure, and effecting vein closure primarily by fibrosis, not thrombosis. Although the significance of laser–wall contact in the actual mechanism of action of EVLA has been challenged in the context of intellectual property disputes over the patent, the direct contact theory is supported by many parameters of the EVLA procedure, including the light-absorbing properties of blood, technical features of the EVLA procedure itself, patterns of injury observed in post-EVLA vein segments and direct thermal temperature studies.

The chromophore properties of haemoglobin support direct contact as a likely primary mechanism of laser-induced endovenous photothermolysis. Excluding 1320 nm lasers, the wavelengths of light used for EVLA are rapidly absorbed by haemoglobin, with near complete attenuation of the beam within 0.2–0.3 mm of the light-emitting surface[16] when fired into a blood interface. This means that the beam penetration into the blood column is very limited, and that contact between the fibre and vein is needed to ensure that the zone of active thermal heating is actually able to reach the vein wall.

In actual clinical practice, several features of the standard EVLA procedure serve to promote and ensure that contact between the vein and laser fibre indeed occurs and is maintained for the majority of the treatment. Vasospasm, a physiological reaction to the insertion and presence of a foreign body within a vein, occurs to some degree in most cases of EVLA and acts to contract the vein circumferentially down onto the laser fibre. Manoeuvres to empty the vein, such as Trendelberg positioning of the patient and application of manual pressure over the target vein segment, also assist in vein–fibre apposition. Finally, tumescent anaesthesia injected into the saphenous space and/or the perivenous space promotes collapse of the vein walls onto the laser fibre. Given the technical aspects of how EVLA is performed, it is difficult to envision a routine treatment situation in which the target vein fails to contact the laser fibre during the majority of the procedure.

To further investigate the causal role of thermal damage in EVLA, the author performed several tests in an *in vitro* system designed to isolate the effects of contact. This system consisted of a segment of blood-filled bovine saphenous vein mounted upon two hollow-bore cannulae through which a laser fibre was inserted and retracted. The vein and cannulae were sealed in a closed transparent chamber that could be filled with saline and pressurized to simulate tumescent anaesthesia. The laser fibre was mounted inside a balloon catheter which, when inflated, centered the fibre in the vessel lumen and prevented contact between the vein wall and the fibre. A diagram of the apparatus and image of the centering system are presented in Figure 4. Vein segments were subjected to EVLA performed with 810 nm and 980 nm wavelength light, fired continuously with a pullback rate of 2 mm/second. The EVLA was performed under conditions of balloon inflation without tumescent effect, balloon inflation with tumescent effect and tumescent effect without balloon inflation (condition of maximum contact). The vein specimens were sectioned and sent for histopathological analysis and reviewed with a pathologist.

These tests revealed that under conditions that prevented laser–wall contact (balloon inflation), EVLA produced mild thermal damage in the form

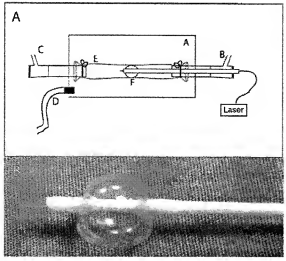

Figure 4 Schematic diagram of experimental apparatus: (A) Transparent saline-filled chamber; (B) blood injection port; (C) blood drainage port; (D) saline injection port to pressurize chamber; (E) blood-filled vein segment; (F) centering system with laser fibre mounted inside balloon catheter

of partial thickness collagen denaturing. The damage was mild, not transmural and patchy in distribution. These findings are presented in Figures 5a and b. In contrast, conditions designed to promote laser–vein contact (tumescent effect with deflated centering system) produced a strikingly different pattern of thermal damage, characterized by focal vein wall perforation and troughing, circumferential transmural collagen denaturing and carbonization. The injury distribution was notable for a focal area of severe transmural destruction, associated with a lesser degree of collagen denaturing and damage extending laterally from the epicentre of injury (Figure 5c). These findings are analogous to the histopathological changes described in the existing literature on explanted post-EVLA veins and support the theory that direct wall contact is the primary mechanism of action of EVLA in the clinical setting.

A recent investigation by Disselhoff *et al.*[11] elegantly illustrates the photothermolytic process that occurs during EVLA. In this study, EVLA was performed in an *in vitro*-explanted saphenous vein system with simultaneous intravascular thermal monitoring via a multithermal couple catheter that could record a maximum temperature of 300°C. The investigators observed three distinct phases for the photothermolysis process during EVLA. Initially, the light energy was absorbed by haemoglobin resulting in the formation of a coagulum around the fibre tip. At this phase, intravascular temperatures were found to be in 70–80°C range.

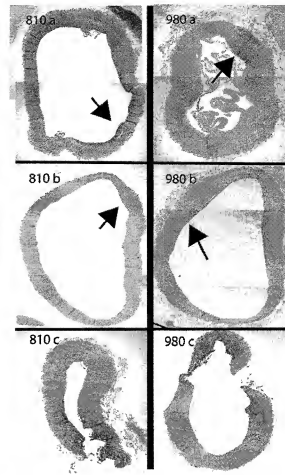

Figure 5 Endovenous laser ablation (EVLA) of blood-filled bovine saphenous vein at 810 nm and 980 nm laser energy under three conditions: (a) Centered laser without tumescent effect; (b) centered laser with tumescent effect; (c) uncentered laser with tumescent effect. With the use of centering device, mild patchy collagen denaturing (black arrows) was present for both wavelengths. Without the centering device, severe bilateral charring, ablation and perforation occurred. Note: the zone of denatured collagen radiating away from the epicenters of maximum thermal damage

At 100°C, water vaporized and steam formation occurred, with temperatures never exceeding 110°C. Following this phase, temperatures at the laser tip rose to the maximum recording level (300°C) as black carbon formed in the coagulum. This phase of intense heat production at the fibre tip was subsequently sustained throughout the remainder of the laser firing period. Although the thermal couple catheter could only record temperatures up to 300°C, the investigators noted melting of the glass fibre tip, a phenomenon that implied fibre tip temperatures in excess of 1200°C, the melting point of glass. Histological analysis of the vein segments showed carbonized trough formation with

minimal damage between the troughs, again implying that the main damage occurs along the path of laser–wall contact and that the dominant mechanism of photothermolysis damage in EVLA is by direct wall contact.

Fibrotic versus thrombotic vein closure

Following an endovenous thermal insult, both thrombosis and fibrosis can be invoked as potential mechanisms of vein closure. While it is certainly likely that both processes are in play to some degree during the post-EVLA healing process, several observations strongly support fibrosis over thrombosis as the primary mechanism of vein occlusion.

Acute venous thrombosis typically presents with clinical symptoms of significant pain, erythema and swelling, and with the sonographic appearance of a hypoechoic and acutely expanded lumen. In contrast to these phlebitic changes, within one week following EVLA, the vein demonstrates a hyperechoic lumen and reduction in vein diameter. Weiss *et al.*[10] noted that vein diameter reduction occurred in response to endovenous thermal ablation by either laser or radiofrequency methods, and noted that this luminal change was related to collagen contraction. In the EVLA specimens, the collagen contraction and thermal effects were eccentrically present on the side of the vein in contact with the laser, again supporting the theory of direct contact as the mechanism of action for EVLA.

The overall 94–97% long-term closure success rate of EVLA also argues against thrombosis as a primary closure mechanism after EVLA. Primary thrombotic occlusion with mild endothelial injury, as seen in sclerotherapy of great saphenous veins, has been associated with recanalization rates of up to 50%.[17] Similarly, the natural history of deep venous thrombosis is a recanalization rate of 50% or more at one year.[18] The high permanent closure rate of EVLA with minimally associated phlebitic symptoms strongly suggests that the vein occlusion occurs by some other means, i.e. thermal denaturing and contraction of the vein wall collagen followed by fibrotic obliteration of the lumen.

Conclusion

The preponderance of histological, procedural and anatomical evidence indicate that the primary mechanism of action of EVLA is a significant transmural thermal injury mediated by direct contact between the laser and the vein wall. The studies and observations discussed above indicate that EVLA offers no exception to the expected spectrum and sequence of tissue response to heating that has been well-described with regards to other medical lasers, i.e. collagen denaturing, tissue desiccation with steam production, followed by tissue vaporization and carbonization. Steam production certainly occurs as an expected early step in the photothermolytic process, but it accounts for <2% of the delivered energy dose. Steam production occurs at 100°C, a temperature far below what has been observed experimentally in EVLA, and below that which is required to produce the severe transmural tissue damage, troughing deformities and carbonization consistently seen in post-EVLA pathological specimens. Given these facts, steam cannot be invoked as the primary mechanism of action for thermal damage during EVLA.

The likely mechanism of action in EVLA involves initial energy absorption potentiated by the chromophore effect of a small amount of residual blood inside the predominantly emptied vein. This sets off the sequence of events that with continued energy delivery leads to the subsequent carbonization along the endothelial surface and vein wall. The black carbon creates a second intensely light-absorbing interface, which in its turn perpetuates high temperatures peaking in excess to 1000°C at the laser tip throughout the remainder of the laser firing period. It is this second intense and ongoing photothermolytic event that acts directly upon the vein wall to produce the major damage leading to fibrotic vein occlusion.

Currently, the optimal EVLA energy dose and treatment parameters for durable vein closure while minimizing side-effects are not known. Several studies have shown that increasing fluence is associated with better long-term results.[19–21] This makes intuitive sense, as higher energy dose likely causes more extensive irreversible damage. However, durable vein closure has been reported with energy doses <33 J/cm and treatment failures have been reported at doses as high as 120 J/cm.[21,22] Clearly, many factors other than energy dose may affect closure success, including vein diameter, treatment segment length, branch inflow patterns and central venous pressure.[23] Understanding the mechanism of laser action may potentially help guide refinements of equipment design and procedural approach.

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